Mask blank for use in EUV lithography and method for its production

The present application claims convention priority of German patent application no. 103 17 792.2-51 the whole content of which is hereby explicitly incorporated by reference.

Field of the Invention

This invention relates to a mask blank for use in EUV lithography (extreme ultraviolet lithography) and a method for its production.

Related Art

To achieve ever higher integration densities in microelectronics, it is necessary to use increasingly shorter wavelengths for exposure. It is foreseeable that in future wavelengths of only 13 nanometers or even less will be used in order to produce structures of less than 35 nanometers. In this context, the production of masks for lithographic exposure is of key importance. Masks must be virtually defect-free because otherwise the slightest errors in the mask will be replicated on every chip. All sources that could result in contamination of a mask must be excluded to the greatest degree possible.

This requires extremely precise techniques for the production of mask blanks and extremely careful holding and handling of mask blanks in order to avoid abrasion and particle formation to the greatest degree possible. In view of the risk of contamination of mask blanks, even the slightest improvements to methods of this kind can result in significant improvements to quality in semiconductor production. Therefore, it is not surprising that the methods considered for the production and handling of mask blanks can be relatively complicated and expensive, because the objective of semiconductor production is always to achieve the highest possible integration density with the lowest possible reject rate.

Summary of the Invention

It is an object of the present invention to provide a mask blank for use in EUV lithography with which the risk of contamination and mask errors can be reduced even further. It is a further object of the intention of the present invention to provide a method for the production of a mask blank of this kind.

According to the present invention, a mask blank for use in EUV lithography is provided whereby the mask blank comprises a substrate with a front side and a rear side and a coating is applied to the front side for use as a mask in EUV lithography. According to the present invention, the rear side of the substrate comprises an electrically conductive coating. This enables a mask blank to be provided with a surprisingly simple design exhibiting advantages with regard to the risk of contamination and particle formation. According to the present invention, the substrate preferably comprises a material with an extremely low coefficient of thermal expansion.

A mask blank according to the present invention may be held at the back and over large areas by means of an electrostatic holding device (electrostatic chuck). Because the electrostatic holding device is in contact with a large area of the rear side of the substrate, only low holding forces are necessary. These result in turn in less abrasion and hence in a lower risk of contamination. In addition, a mask blank according to the invention may be held and handled very gently. An electric potential applied to the electrostatic holding device and/or to the rear side of the mask blank can be advantageously controlled and gently switched on and off. This enables sudden applications of force to the mask blank to be avoided to a large extent, which results in even less abrasion and even lower particle formation. The large area of contact between the mask blank and the electrostatic holding device may also be used to pull the mask blank straight, for example, if it is bent or under tension, in order thus to reduce stress.

Preferably, the resistance of the electrically conductive coating to abrasion from a cloth according to DIN 58196-5 (German Industry Standard) falls into at least category 2. Even if the mask blank or a mask produced therefrom is to be held by hand or by means of handling tools during semiconductor production, for example, during replacement or maintenance work, or if the blank or mask is to be used for further process stages, there is virtually no abrasion because the coating on the rear side is so abrasion-resistant.

Preferably, the resistance of the electrically conductive coating to abrasion from an eraser according to DIN 58196-4 (German Industry Standard) falls into at least category 2. Even if the mask blank or a mask produced therefrom is to be brushed against or held during semiconductor production, for example by hand or using a tool, or if the blank or mask is to be used for further process stages, according to the invention there is virtually no abrasion because the coating on the rear side is so abrasion-resistant.

Preferably, the adhesive strength of the electrically conductive coating in an adhesive tape test according to DIN 58196-6 (German Industry Standard) corresponds to a detachment or delamination of substantially 0%. If an adhesive object should ever come into contact with a mask blank or a mask produced therefrom, for example during replacement or maintenance work, virtually no part of the electrically conductive coating on the rear side will become detached or delaminated; otherwise this would result in contamination and troublesome abrasion. Overall, therefore, it is established that, advantageously, the mask blank according to the invention or a mask produced therefrom may be handled reliably and without maintenance problems.

Preferably, the substrate comprises a material with an extremely low coefficient of thermal expansion, which, for example, may be modified silica glass or modified ceramic glass. For the purposes of this patent application, the term 'material with an extremely low coefficient of thermal expansion' should be interpreted to mean that, in the specified temperature range, a material which does not undergo any significant expansion or at least does not undergo extensive thermal expansion. Preferably, in the temperature range from approximately 0 to 50 degrees Celsius, the material with an extremely low coefficient of thermal expansion has a thermal expansion of less than approximately ±100 ppb/K, more preferably of less than approximately ±30 ppb/K and even more preferably less than approximately ±5 ppb/K, because, in the said ranges, mask blanks may be produced with particularly advantageous properties, in particular with respect to use in a lithographic exposure method and the abrasion resistance of the layers.

Regarding the properties of the zero-expansion materials preferred for use according to the present invention, reference is made by way of example to the following applications, the

contents of which are expressly incorporated in this application by reference: DE-OS-19 02 432, US 4,851,372, US 5,591,682 and DE 101 63 597.4.

Corning® 7971 which is an ULE (ultra low expansion) material comprising titanium silicate glass (92.5% SiO_2 and 7.5% TiO_2) can also be used as the material with an extremely low coefficient of thermal expansion. It is produced by mixing pure liquid silicon tetrachloride and titanium tetrachloride together and delivering the vapours to a furnace, where they react chemically. The glass droplets are deposited on a spinning turntable. It takes one week to produce a blank approximately 170 cm in diameter and 15 cm thick. The glass composition obtained in this way is characterised by an ultra-low coefficient of thermal expansion.

In order to achieve adequate optical properties, a coating is applied at least to the front side of the mask blank, the said coating comprising a system of dielectric double layers, in particular of molybdenum silicon double layers, and one chromium layer or one other layer which absorbs EUV light. In this way, a mask blank with surprisingly high abrasion resistance may be produced which is suitable for use in EUV lithography, in particular with wavelengths down to approximately 13 nanometers.

Preferably, the dielectric double layers are applied by ion-beam-assisted deposition, in particular by ion-beam-assisted sputtering, which results in extremely homogeneous and defect-free layers and hence ensures that the coating has a high degree of reflectivity. Overall, this enables extremely precise imaging optics and masks to be provided. With regard to the coating method, reference is made to the applicant's co-pending US patent application serial no. 10/367,539 with the title 'Photo Mask Blank, Photo Mask, Method and Apparatus for Mask Blank, Photo Mask, Method and Apparatus for Manufacturing of a Photo Mask Blank' with a filing date of 13 February 2003, the contents of which are expressly incorporated in this application by reference.

A mask blank can be produced in a surprisingly simple way in that the coatings on the front side and the rear side are substantially identical or identical in sections. This means that identical coating technology and process stages may be used for both the front side and the rear side of the mask blank. This saves time on their production and reduces the risk of contamination because process chambers or similar in which the mask blank is coated do not necessarily have to be opened and the mask blank does not necessarily have to be transferred

to another process chamber. Instead, the mask blank may be coated on the front and rear sides or coated in sections in the same coating process.

To enable the mask blank to be gripped and held even more reliably by an electrostatic holding device, the resistivity of the electrically conductive coating with a layer thickness of approximately 100 nm is at least approximately 10^{-3} Ωcm, more preferably at least approximately 10^{-4} Ωcm, because this enables the mask blank to be held and gripped even better, even more preferably at least approximately 10^{-5} Ωcm, because this enables the mask blank to be held and gripped even better, even more preferably at least approximately 10^{-6} Ωcm, because this enables the mask blank to be held and gripped even better, even more preferably at least approximately 10^{-7} Ωcm, because this enables the mask blank to be held and gripped even better and even more preferably at least approximately 10^{-8} Ωcm, because this enables the mask blank to be held and gripped even better. With a layer thickness of approximately 100 nm, a resistivity of at least approximately 10^{-5} Ωcm has been found to be quite particularly preferable.

The present invention also provides a method for the production of a mask blank for use in EUV lithography whereby the mask blank comprises a substrate made of a material with an extremely low coefficient of thermal expansion with a front side and a rear side in which a coating is applied to the front side for use as a mask in EUV lithography and an electrically conductive coating is applied to the rear side.

Detailed Description of Preferred Embodiments

The following will describe preferred examples of embodiments according to the present invention by way of examples. When studying the following examples of embodiments, further features, advantages and modifications according to the present invention will be evident to a person skilled in the art.

The mask blank according to the present invention comprises a substrate which comprises a highly homogeneous optical glass, silica glass, ceramic glass or a comparable material. With regard to the thermal expansion, the substrate is preferably virtually a zero-expansion material. The mask blank preferably has a rectangular shape, for example with an edge length

of approximately 15 cm. Obviously, the mask blank may also have another geometric shape, for example circular. The substrate is polished with an accuracy of only a few tenths of a nanometer. As is known from the prior art, on the front side a system of dielectric double layers is formed which satisfies the Bragg reflection condition for the amplification of reflected radiation by constructive interference. An example of an exposing wavelength of 13.4 nanometers according to the present invention comprises approximately 50 molybdenum silicon double layers with a molybdenum layer thickness of approximately 2.8 nanometers and a silicon layer thickness of approximately 4 nanometers. Suitable dielectric multilayer systems matching the wavelength used for exposure are known to a person skilled in the art.

Applied to the surface of the dielectric multilayer system is a metal mask, in particular a chromium mask or another EUV absorber to absorb the exposing radiation. The metal layer, in particular the chromium layer, is preferably structured or patterned. The front side of the substrate is preferably overall electrically conducting.

According to the present invention, an electrically conductive coating is applied to the rear side of the substrate. This is preferably applied to the entire surface of the rear side, but can, however, also be applied in a suitable way to sections of the rear side, for example in a ring shape, as a square, for example matched to the outside contour of an electrostatic holding device (electrostatic chuck).

Preferably, the electrically conductive coating is applied to the rear side of the substrate by means of process stages which are identical to those used to produce the corresponding electrically conductive coating on the front side of the substrate. In this way, the mask blank may be produced at least in sections in one single operational step. This can mean that there is no requirement to break up a protective atmosphere or a vacuum in a deposition chamber. Obviously, a dielectric multilayer coating may also be applied to the rear side of the substrate – preferably, this will be identical to the multilayer coating applied to the front side of the substrate.

The substrate and coatings are designed for exposure wavelengths in the ultraviolet part of the spectrum for use in EUV lithography (extreme ultraviolet lithography). One possibility for the future of EUV lithography is the use of wavelengths down to approximately 13 nanometers.

The coatings on the front side of the mask blank are at first structureless or unpatterned. In a subsequent process stage, which may be performed either at the manufacturer's premises or at the premises of the recipient of the mask blank, the coatings are suitably structured or patterned so that a mask for EUV lithography may be provided. The mask blank or mask may be covered with a resist film, for example of a photoresist or a protective lacquer.

Because the rear side of the substrate has an electrically conductive coating, the mask blank may be held and handled using an electrostatic holding device. The electrically conductive coating on the rear side of the mask blank enables electrostatic charges from the mask blank, for example during transportation or handling, to be avoided in an even more effective way.

In principle, all metallisation techniques providing an adequate metallisation quality suitable for the coating of the rear side of the substrate are possible. Ion-beam-assisted deposition, in particular ion-beam-assisted sputtering, has been found to be particularly suitable. With this coating technology, an ion beam is directed onto a target whose material peels off into a vacuum. The target is located in the vicinity of the substrate to be coated and the substrate is coated by the detached target substance by sputtering. Even if this coating method is relatively complex and expensive, it has been found to be particularly suitable for coating masks or mask blanks because the layers applied are particularly homogeneous and defect-free. Ion-beam-assisted deposition may be used to apply a metal or a mixture of two or more metals or dielectrics. As regards the details of the ion-beam-assisted deposition of metals and dielectrics, reference is made to the applicant's co-pending US patent application serial no. 10/367,539 with the title 'Photo Mask Blank, Photo Mask, Method and Apparatus for Mask Blank, Photo Mask, Method and Apparatus for Manufacturing of a Photo Mask Blank' with a filing date of 13 February 2003, the contents of which are expressly incorporated in this application by reference.

The electrically conductive coatings applied in this way to the rear side of the substrate are characterised by several advantageous properties, particularly with regard to abrasion and resistance, which will be described in the following with reference to preferred exemplary embodiments which were produced and characterised in a sequence of relatively complex experiments.

First Exemplary Embodiment

A chromium layer with a thickness of approximately 50 nanometers to approximately 100 nanometers was applied to the rear side of a mask blank by means of ion-beam-assisted sputtering. The resistance of the coating on the rear side to abrasion caused by a cloth was evaluated according to DIN 58196-5 (German Industry Standard). According to DIN 58196-5 (German Industry Standard), the specimen is tested in relation to the specified degree of severity (H25: 25 cycles, H50 50 cycles). A stamp with a planar contact surface of 10 mm diameter, over which a cloth comprising 4-ply gauze bandage according to DIN 61631 – MB – 12 CV/CO is stretched, is drawn to-and-fro for at least 20 mm (one cycle) over the surface of the specimen with a force of 4.5 N.

Following the application of the load, the specimen is cleaned with cotton wool and solvent according to DIN 58752 (German Industry Standard). The surface is subjected to a visual evaluation of reflection and transmission without magnification in a box against a matt-black background at different angles by turning and tilting the specimen in the light of a 100 W filament lamp. The lamp-specimen distance should be approximately 30 to 40 cm; the specimen-eye distance should be approximately 25 cm.

The evaluation according to DIN 58196-6 (German Industry Standard) takes the form of an evaluation of the visibly identifiable layer destruction. The result is assigned to one of the five resistance classes defined in the standard. The resistance classes may be used to evaluate the layer adhesion. According to DIN 58196-5 (German Industry Standard), Category 1 equals no visible layer damage, Category 2 equals a small amount of scattered light as a result of abrasion traces, Category 3 equals more scattered light identifiable with slight indications of incipient partial damage, Category 4 equals clearly identifiable partial damage to the layer and Category 5 equals coating worn down to the substrate.

The aforementioned substrate was evaluated according to DIN 58196-5 (German Industry Standard). The number of strokes was 25 (degree of severity H25). Twenty specimens were evaluated. All specimens were evaluated as belonging to Category 2 or better according to DIN 58196-5.

Second Exemplary Embodiment

A mask blank such as that described in connection with the first exemplary embodiment was tested with reference to DIN 58196-4 (German Industry Standard) to determine the resistance of the coating on the rear side to abrasion caused by an eraser. DIN 58196-4 describes in detail the preparation of the surface of the eraser used (roughening on a ground glass disc, cleaning with isopropanol) and the conduct of the test (diameter of the abrasion surface 6.5-7 mm, abrasion force 4.5 N, abrasion length 20 mm). The eraser is rubbed over the coating on the rear side. Evaluation takes the form of the subjective evaluation of the visibly identifiable layer destruction. The result is assigned to one of the five resistance classes defined in the DIN 58196-5. The resistance classes may be used to evaluate the layer adhesion.

Category 1 equals no identifiable layer damage, Category 2 equals a small amount of scattered light identifiable so that the abrasion trace is identifiable as such, Category 3 equals more scattered light identifiable with slight indications of incipient partial damage, Category 4 equals clearly identifiable partial damage to the layer and Category 5 equals coating worn down to the substrate.

Twenty substrates were evaluated whereby the eraser was rubbed over the rear side coating 20 times. All specimens were evaluated as belonging to Category 2 or better.

Third Exemplary Embodiment

A mask blank such as that described in detail in connection with the first exemplary embodiment was tested using a test method according to DIN 58196-6 (Test of Adhesion Strength using an Adhesive Tape) to determine the adhesion strength of the coating on the rear side. According to DIN 58196-6 (German Industry Standard), the specimen is placed flat on a fixed base (table). Then, a long fresh strip at least 25 mm long from a roll of adhesive tape is stuck onto the surface to be tested by pressing with the finger to ensure there are no bubbles and allowed to protrude over the edge. The adhesive tape should be made of polyester and be at least 12 mm wide. Its adhesiveness should be (9.8 ± 0.5) N relative to a tape width of 25 mm. After 1 minute, the protruding edge of the tape is taken in one hand and pulled off vertically to the test surface while the other hand holds the specimen securely on the base. Depending upon the degree of severity, the adhesive tape is pulled off slowly – within 2 to 3 seconds (degree of severity K1) or suddenly – within less than 1 second (degree

of severity K2). The evaluation takes the form of a subjective evaluation of the visibly identifiable layer destruction which is expressed as a percentage of the detachment caused by the adhesion of the tape to the surface.

Twenty substrates were evaluated. The adhesive tape was pulled off suddenly within less than a second (degree of severity K2). All specimens revealed approximately 0% detachment.

Fourth Exemplary Embodiment

A mask blank such as that described in detail in connection with the first exemplary embodiment was measured using two methods for measuring surface resistance. The following surface resistance values occurred in the centre of the disc. In each case, two measurements were performed for each current.

	Linear van der Pauw method		Linear four-point method	
Current [mA]	Rf [Ohm]	+-	Rf [Ohm]	+-
1	26.2056	0.0108	26.1019	0.0028
2	26.2186	0.0051	26.0941	0.0002
3	26.2218	0.0061	26.0705	0.0003
4	26.2140	0.0030	26.0765	0.0001
5	26.2142	0.0023	26.0788	0.0005
Average	**26.2148**	**0.0060**	**26.0844**	**0.0130**

With an even smaller current of 0.5 mA, starting from the centre point, the following values for surface resistance in Ohm were measured 1 cm from the centre point:

26.2866		26.2703
	26.2728	
26.3068		26.2520

To calculate the resistivity of the layer, the surface resistance should be multiplied by the layer thickness, so that for example a layer thickness of 40 nm produces

26.2728 Ohm x 40 nm = 105 μOhmcm.

The electrical conductivity of the coating on the rear side may be calculated in a similar way.

In the aforementioned examples of embodiments, the sputtered-on chromium layers or EUV-absorbing layers could obviously have different thicknesses, for example in the range from approximately 30 nm to approximately 100 nm, more preferably in the range from approximately 40 nm to approximately 90 nm and even more preferably in the range from approximately 50 nm to approximately 70 nm.

Express reference is made to the fact that the specifications in DIN 51896 (German Industry Standard) are expressly incorporated in this patent application by reference in particular as regards the test procedures and evaluations described therein.

Without further elaboration, it is believed that one skilled in the art can, using the preceding description, utilize the present invention to its fullest extent. The preceding preferred specific embodiments are, therefore, to be construed as merely illustrative, and not limitative of the remainder of the disclosure in any way whatsoever.

In the foregoing and in the examples, all temperatures are set forth uncorrected in degrees Celsius and, all parts and percentages are by weight, unless otherwise indicated.

The entire disclosures of all applications, patents and publications, cited herein and of corresponding German application No. 103 17 792.2, filed April 16, 2003 is incorporated by reference herein.

The preceding examples can be repeated with similar success by substituting the generically or specifically described reactants and/or operating conditions of this invention for those used in the preceding examples.

From the foregoing description, one skilled in the art can easily ascertain the essential characteristics of this invention and, without departing from the spirit and scope thereof, can make various changes and modifications of the invention to adapt it to various usages and conditions.